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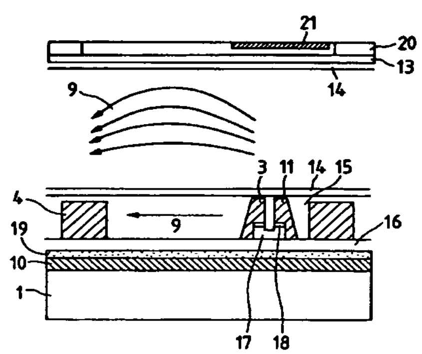
(54) **Active matrix type liquid crystal display apparatus.**

(57) A liquid crystal display apparatus, having a designated drive means composed of a group of electrodes (3, 4) forming pixels in the nXm matrix and active devices, in which the electrodes (3, 4) have a structure with which an electric field parallel to the interface can be applied to the liquid crystal composite layer, and the cell-gap between substrates (1) facing to each other is 6 μm or less and the response time is less than or equal to 100 ms and greater than or equal to 1 ms.

FIG. 3



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BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a liquid crystal display apparatus, and more particulary to an active matrix liquid crystal display apparatus.

DESCRIPTION OF THE PRIOR ART

In the conventional Liquid Crystal Display Apparatus, as for the electrodes for driving the liquid crystal layer, the electrodes are formed on the surface of two substrates, and transparent electrodes are used, each electrode facing to each other. This is because what is used is a display method represented by Twisted Nematic display method in which the liquid crystal layer is driven by applying an electric field in the vertical direction to the surface of the substrate. On the other hand, as for the display method in which an electric field is applied in the direction almost parallel to the surface of the substrate, a display method using comb-type electrodes is disclosed in the Japanese Patent No. 63-21907 (1988) and USP 4345249. In this case, the electrodes are not necessarily selected to be transparent, but non-transparent and metallic electrodes with higher electric conductivity are used. However, in the prior art above, as for the display method in which the electric field is applied in the direction to the surface of the electrode, (which is designated "In-plane switchin metho"), specifically used in the active matrix drive mode, or as for the horizontal electric field method with low voltage drive, the enabling material property of the liquid crystal layer and the device structure are not described in detail.

In the horizontal electric field method, it is required to make the electrode gap wider in order to attain the higher cross-section for the open port, which arises a problem that the necessary drive voltage becomes higher. In addition, in order to allow the mouse as a pointing device to be enabled in the liquid crystal display apparatis, it is required to establish the response time between 150 ms and 200 ms, and for enabling the motion picture resolution, the response time is required to be 50 ms. However, the response of the liquid crystal to the electric field change is genetically slow, it often makes such a problem that the response time of the liquid crystal is slow in various kinds of display methods using Nematic Liquid Crystal. This is not exceptional in the horizontal electric field method. In addition, due to the electrode structure specific to the horizontal electrid field method, the electric field tend not to be fully applied to the liquid crystal, which results in the slower response of the liquid crystal. Thus, some means is required in order to reduce the drive voltage and to enable the mouse compatible and the motion picture resolution.

The object of the present invention is to provide an active matrix type liquid crystal display apparatus which has a high-speed response to allow the mouse as a pointing device or enable the motion picture resolution in the horizontal electric field method.

SUMMARY OF THE INVENTION

In the present invention, the following means are used for solving the above mentioned problems and attaining the above objective.

The present invention includes a pair of substrates, at least one of which is transparent; a liquid crystal composite layer arranged between the substrates; electrodes on the substrates for applying an electric field substantially parallel to the substrates; an orientation control layer for controlling the orientation of the molecule of the liquid crystal; a polarization means; and a drive means; in which the gap between the substrates is less than or equal to 6 mm, and the response time is less than or equal to 100 ms, and greater than or equal to 1 ms.

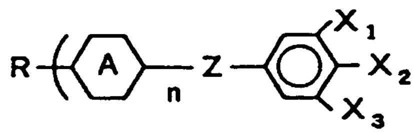
The relationship between the dielectric constant of the liquid crystal composite material layer, ($(\epsilon_{LC})//$: dielectric constant measured in the longitudinal axis of the molecule, $(\epsilon_{LC})\perp$: dielectric constant measured in the tranverse axis of the molecule), and the dielectric constant of the orientation control layer, (ϵ_{AF}) , holds the equation (1).

$$(\epsilon_{LC})// > 2\epsilon_{AF}, \text{ or } (\epsilon_{LC})\perp > 2\epsilon_{AF}, \qquad (1)$$

Further, the relationship between the viscosity of the liquid crystal composite material layer, η, and the elasticity constant of the twist, K_2, holds the equation (2).

$$\eta/K_2 < 4.5 \times 10^{10} \ [s \cdot m^{-2}] \qquad (2)$$

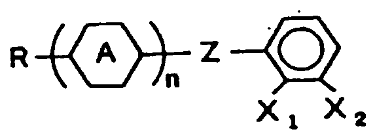
Furthermore, the liquid crystal composite material according to the present invention is made to include liquid crystal chemical compound represented by the general chemical formula (I), in which fluoro group or cyano group, or both of them coexist as an end group.



(I)

In the chemical formula (I), X_1, X_2 and X_3 are fluoro group, cyano group, or hydrogen atom; R is alkyl group or alkoxyl group having the carbon number, 1 to 10 which is replaceable; Ring R is cyclohexane ring, benzene ring, dioxane ring, pyrimidine ring, or [2, 2, 2]-bicyclooctane ring; Z is single bonding, ester bonding, ether bonding, or methylene, or ethylene; and n is an integer, 1 or 2.

Preferably, the liquid crystal composite material may be made so as to include liquid crystal chemical compound represented by the general chemical formula (I), in which fluoro group or cyano group, or both of them coexist as an end group.



(II)

In the chemical formula (II), X_1 and X_2 are fluoro group, cyano group, or hydrogen atom; R is alkyl group or alkoxyl group having the carbon number, 1 to 10 which is replaceable; Ring R is cyclohexane ring, benzene ring, dioxane ring, pyrimidine ring, or [2, 2, 2]-bicyclooctane ring; Z is single bonding, ester bonding, ether bonding, or methylene, or ethylene; and n is an integer, 1 or 2.

Preferably, the retardation of the liquid crystal composite material layer, $d \cdot \Delta n$, may be greater than or equal to 0.21 μm, and less than or equal to 0.36 μm.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1(a) to 1(d) show the operation of the liquid crystal in the liquid crystal display apparatus of a horizontal electric field type.

FIG. 2 is a plane view of the unit pixel in the liquid crystal display apparatus of a horizontal electric field type.

FIG. 3 is a cross-section view of the unit pixel in the liquid crystal display apparatus of a horizontal electric field type.

FIG. 4 shows the angle ϕ_P defined by the polarization transmission axis, the angle ϕ_{LC} defined by the liquid crystal molecule longitudinal axis (optical axis) at the interface neighborhood, and the angle ϕ_R defined by the condensive axis in the phase shifter plate, each with respect to the electric field direction in the embodiments 1 to 5 and the comparison examples 1 and 2.

FIG. 5 is the definition of the response time.

FIG. 6 is a diagrammatic picture showing the diffraction of the electric field at the interface on the dielectric layer.

FIG. 7 is a graph showing the relationship between the response speed and the ratio of the viscosity of the liquid crystal to the elasticity constant of the liquid crystal is shown in the embodiments and the comparison examples of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 4, the angle ϕ defined by the polarization transmission axis, the angle ϕ_{LC} defined by the liquid crystal molecule longitudinal axis (optical axis) at the interface neighborhood, the angle ϕ_R defined by the condensive axis in the phase shifter plate inserted between a couple of polarizers. The angle ϕ_P and ϕ_{LC} are

expressed selectively in terms of ϕ_{P1}, ϕ_{P2}, ϕ_{LC1} and ϕ_{LC2} as there are a couple of polarizers and a couple of liquid crystal interfaces.

FIGS. 1(a) and 1(b) show side cross-section views showing the operation of the liquid crystal in the liquid crystal panel, and FIGS. 1(c) and 1(d) show front views of them in the present invention. In FIGS. 1(a) to 1(d), active devices are not shown. In addition, though a plurality of pixels are formed with striped electrodes in the present invention, a partial view of a single pixel is shown in FIGS. 1(a) to 1(d). The side cross-section view when voltage is not applied is shown in FIG. 1(a) and the front view is shown in FIG. 1-(c). The linear electrodes 3 and 4 is formed inside a couple of transparent substrates 1, and a couple of orientation films 6 are coated on the substrates 1 so that they face to each other. Liquid crystal composite material is inserted between the films. The liquid crystal molecule 5 shaped in line is oriented so that the angle ϕ_{LC} of the longitudinal axis of the molecule between the longitudinal direction of the Y electrode shaped in stripe may be maintained to be an adequate angle such as $45° \leq |\phi_{LC}| < 90°$. For the explanation below, the orientation direction of the liquid crystal molecule on the upper and lower interfaces is assumed to be parallel to each other, that is, $\phi_{LC}1 = \phi_{LC}2$. The dielectric anisotropy of the liquid crystal composite material is assumed to be positive. Next, when the electric field 9 is applied, as shown in FIGS. 1 (b) and (d), the axis of the liquid crystal molecule is made oriented in the direction of the electric field. By placing the polarizer 2 with a designated angle 8, it is enabled that the optical transmission index can be modulated by applying and changing the electric field. Thus, the display operation for defining contrast is allowed without transparent electrodes. Though the dielectric anisotropy of the liquid crystal composite material is assumed to be positive, it may be selected to be negative. In case of negative dielectric anisotropy, as for the initial orientation of the liquid crystal molecule, the angle ϕ_{LC} is maintained to be an adequate angle to the vertical direction to the longitudinal axis of the striped electrode such as $0° < |\phi_{LC}| \leq 45°$.

The response time in the horizontal electric field method can be derived by solving the torque balance equation in terms of elastic torque, electro-magnetic torque and viscous torque. The rising-up time and the falling-down time of the liquid crystal result in the following expression.

$$\tau_{rise} = \gamma 1/(\epsilon_0 \Delta\epsilon E^2 - \eta^2 K_2/d^2), \qquad (3), \text{ and}$$
$$\tau_{fall} = \tau_1 d^2/\eta^2 K_2 = \gamma 1/\epsilon 0 \Delta\epsilon E_c^2, \qquad (4),$$

where

τ_{rise} is the rising-up time,
τ_{fall} is the falling-down time,
$\gamma 1$ is viscosity coefficient,
K_2 is the elastic constant of the twist,
d is the cell gap,
$\Delta\epsilon$ is the dielectric anisotropy,
ϵ_0 is the vacuum dielectric index,
E is the electric field intensity, and
E_c is the threshold electric field intensity.

The above equation shows that the response time can be reduced by making smaller the cell gap d between the substrates facing to each other. As making the cell gap d smaller, the falling-down time decreases proportionally to the reciprocal of the square of the cell gap d. On the other hand, the second term of the dominant of the expression of the rising-up time is smaller than its first term, the rising -up time is not extended even by making the cell gap smaller.

Therefore, to make the cell gap between the substrates facing to each other 6 µm or less as described in means 1 provides a prospective way to establish the response time less than or equal to 100ms, preferably, less than or equal to 5µm. In the above definition, as shown in FIG. 5, the response time is defined to be the time period while the transmission ratio changes required for the 90% fraction of its switching operation between the minimum voltage and the maximum voltage.

As described in means 2, by means that the relationship between the dielectric constant of the liquid crystal composite material layer, ($(\epsilon_{LC})//$: dielectric constant measured in the longitudinal axis of the molecule, $(\epsilon_{LC})\perp$: dielectric constant measured in the shorter axis of the molecule), and the dielectric constant of the orientation control layer, (ϵ_{AF}), is made to hold the equation $(\epsilon_{LC})// > 2\epsilon_{AF}$, or $(\epsilon_{LC})\perp > 2\epsilon_{AF}$, and that the relationship between the viscosity of the liquid crystal composite material layer, h, and the elasticity constant of the twist, K_2, holds the equation, $\eta/K_2 < 45$ [Gs/(m•m)], it will be appreciated that a liquid crystal display apparatus with high-speed response can be established. In the ordinary horizontal electric field method, as the thickness of the electrode is smaller than the thickness of the liquid crystal

composite material layer, the electric field completely parallel to the interface between the liquid crystal and the orientation layer can not completely applied to the liquid crystal layer. This incomplete horizontal electric field makes worse the efficiency in switching the liquid crystal on the interface. As the refraction of the electric field between the two-layered dielectric material layer is so formed as shown in FIG. 6, by making the dielectric constant ϵ_{LC} of the liquid crystal larger than the dielectric constant ϵ_{AF} of the orientation layer, preferably making eLC twice larger than ϵ_{AF}, what can be applied to the liquid crystal is a horizontal electric field which is more parallel to the interface between the liquid crystal and the orientation layer. Therefore, a necessary horizontal electric field can be supplied efficiently to the liquid crystal for switching the liquid crystal on the interface. In addition, with more intensive study in which the viscosity h of the liquid crystal is modified to be smaller or the elasticity constant K_2 of the twist is modified to be larger, the high-speed response which enables the mouse compatible or the motion picture resolution can be attained when the ratio between the viscosity and the elasticity constant is 45 [Gs/(mm)].

Furthermore, it is proved that the liquid crystal shown in the means 3 above is adopted to the conditions given by the means 1 and 2, and that the high-speed response which enables the mouse compatible or the motion picture resolution can be attained. As the tritluoro-type liquid crystal having a molecular structure with fluoro group at the molecular end has a larger dielectric anisotropy $\Delta\epsilon$, about 7, while smaller viscosity η between 20cp and 30 cp, it is also possible to make the drive voltage smaller and the response time shorter by adding this type of liquid crystal to another liquid crystal. More instantly, trans-4-heptyl-(3, 4, 5-trifluorophenyl) cyclohexane; 1, 2, 6-trifluoro-4-[trans--4-(trans-4-propylcyclohexyl) cyclohexyl] benzene; Trans-4-propyl-(3, 4, 5-trifluorobiphenyl-4'-yl) cyclohexane; 2-(trans-4-propyl-cyclohexyl)-1-[trans-4-(3, 4, 5-trifluorophenyl) cyclohexyl] ethane; 3, 4, 5-trifluorophenyl-trans-4-bentylecyclohexylcarboxylate; Trans-4-heptyl-(3, 4-difluorophenyl) cyclohexane; 1, 2-difluoro-4-[trans-4-(trans-4-propylcyclohexyl) cyclohexyl] benzene; Trans-4-propyl-(3, 4, difluorobiphenyl-4'-yl) cyclohexane; 2-(trans-4-propylecyclohexyl)-1-[trans-4-(3, 4-difluorophenyl) cyclohexyl] ethane; 3, 4-difluorophenyl-trans-4-bentylecyclohexylcarboxylate;Trans-4-heptyl-(4-cyanophenyl) cyclohexane; 1, 2-dicyano-4-[trans-4-(trans-4-propylcyclohexyl) cyclohexyl] benzene; Trans-4-propyl-(3, 4-dicyanobiphenyl-4'-yl) cyclohexane; 2-(trans-4-propylcyclohexyl)-1-[trans-4-(3, 4-dicyanophenyl) cyclohexyl] ethane; 3, 4-dicyanophenyl-trans-4-bentyl-cyclohexylcarboxylate; 4-cyano-3-fluorophenyl-trans-4-propylcyclohexylcarboxylate. The present invention does not exclude compounds other than above. The liquid crystal compound having fluoro group at the ortho position in its cyano end group, represented by 4-cyano-3-fluorophenyl-trans-4-propylcyclohexylcarboxylate, is known to be material which does not tend to form dimer to cancel the dipole momentum. As such liquid crystal compound has larger dielectric constant and lower viscosity, it is effective to apply this kind of compound to the high-speed driving operation in the horizontal electric field method.

Furthermore, it is proved that the liquid crystal shown in the means 4 above is adopted to the conditions given by the means 1 and 2, and that the high-speed response which enables the mouse compatible or the motion picture resolution can be attained. More instantly, trans-4-heptyl-(2, 3-difluorophenyl) cyclohexane; 2, 3-difluoro-4-[trans-4-(trans-4-propylcyclohexyl) cyclohexyl] benzene; Trans-4-propyl-(2, 3-difluorobiphenyl-4'-yl) cyclohexane; 2-(trans-4-propylcyclohexyl)-1-[trans-4-(2, 3-difluorophenyl) cyclohexyl] ethane; 2, 3-difluorophenyl-trans-4-bentylecyclohexylcarboxylate;Trans-4-heptyl-(2-cyano-3-fluorophenyl) cyclohexane; 2-cyano-3-fluoro-4-[trans-4-(trans-4-propylcyclohexyl) cyclohexyl] benzene; Trans-4-propyle-(2-cyano-3-fluorobiphenyl-4'-yl) cyclohexane; 2-(trans-4-propylcyclohexyl)-1-[trans-4-(2-cyano-3-fluorophenyl)cyclohexyl]ethane;2-cyano-3-fluorophenyl-trans-4-bentylecyclohexylcarboxylate. The present invention does not exclude compounds other than above.

In the above described means for driving with high-speed response, from the view point that the overall design of the display device should satisfy many aspects of characteristics and performances other than response time, such as brightness and contrast ratio, the retardation of the liquid crystal, $d\bullet\Delta n$, is determined, for example, as follows. In case of displaying in multiple diffraction mode as described before, the intensity of the transmitted light is defined by the following equation when arranging a couple of polarizers in cross-Nicole.

$$I/I_0 = \sin^2(2\alpha)\bullet\sin^2(\eta d\bullet\Delta n/\lambda)\ , \qquad (5)$$

where

a is the angle defined by the effective light axis of the liquid crystal layer and the polarization transmission axis;

d is the cell gap;

Δn is the anisotropic property of the refractive index of the liquid crystal; and

λ is the wavelength of light.

In order to obtain the normally-close characteristic in which the display pixel takes a dark state when low-voltage applied, and the display pixel takes a bright state when high-voltage applied, as for the layout arrangement of the polarizers, the transmission axis of one polarizer may be taken to be almost parallel to the orientation direction of the liquid crystal molecule (rubbing axis), which means $\phi_{P1} = \phi_{LC1} = \phi_{LC2}$, and the transmission axis of the other polarizer may be taken to be vertical to the rubbing axis, which means $\phi P1 = \phi_{P2} = 90°$. When the electric field is not applied, as a in the equation (5) is 0, the light transmission index I/I_0 is also 0. In contrast, when the electric field is applied, a increases as the light intensity increases, and thus, the light transmission index I/I_0 takes its maximum value at $a = 45°$. In this case, assuming that the wavelength of light is 0.555 μm, the effective $d_{eff} \cdot \Delta n$ may be taken to be 0.28 μm, the half of the wavelength of light, in order to maximize the transmission index with no color tone. As the liquid crystal molecules are fixed in the neighboring area of the interface in the actual cell, d_{eff} is less than the cell gap d. Therefore, in order to attain the higher transmission index and the whiteness of the display emission light for the display pixel in the normally-close characteristics taking a bright state in the multiple refraction mode, $d \cdot \Delta n$ is allowed to taken to be 0. 30 μm a little larger than the half of the wavelength of light. In the actual use, as there is variable margin, $d \cdot \Delta n$ is allowed to taken to be between 0.21 μm and 0.36 μm.

From the view point described above, by making Δn, the anisotropic property of the refractive index of the liquid crystal used, relatively large, and setting the retardation, $d \cdot \Delta n$, between 0.21 and 0.36 μm as described in means 5 above for higher contrast, the gap between the substrates facing to each other is necessarily selected to be small, which may lead to the prospective means for high-speed response.

As described in formula (3) and (4), it is advantageous for high-speed response to select the liquid crystal with lower viscosity. It is also possible to make the response faster by making the absolute value of the dielectric anisotropy of the liquid crystal, $|\Delta\epsilon|$, as larger as possible. This owes that the interactive energy between the electric field and the liquid crystal becomes larger.

With embodiments below, the present invention will be described more in detail.

[Embodiment 1]

FIG. 2 shows a plane view of the unit pixel in the first embodiment of the present invention. FIG. 3 shows a cross section view of FIG. 2. The scanning electrode 10 composed of Al is formed on the polished glass substrate 1, and the surface of the scanning electrode is coated with the anodized film 19 of alumina. The gate nitridation layer 16 (gate SiN) and the amorphous Si layer (a-Si) 17 are formed so as to cover the scanning electrode 10. The n-type a-Si layer 18, the source electrode 3 and the picture signal electrode 11 are formed onto the a-Si layer 17. In addition, the common electrode 4 is attached onto the layer identical to the source electrode 3 and the picture signal electrode 11. As for the structure of the source electrode 3 and the picture signal electrode 11, as shown in FIG. 1, the extension of the these electrodes is parallel to the common electrode 4 formed in stripe and intersects the scanning signal electrode 10 at right angle, and thus, thin film transistors (FIGS. 2 and 3) and the metallic electrodes are formed on one of the substrates. With these transistors and electrodes, the electric field is developed between the source electrode 3 and the common electrode 4 on one of the substrates so that the extention direction 9 of the developed electric field may be almost parallel to the interface of the substrate. The individual electrodes on the substrate are composed of aluminum, but the selection of metal is not limited to aluminum but allowed to be chromium or copper and so on. The number of pixels is selected to be 40 (X3) X30 (that is, n = 120, and m = 30). The horizontal pixel pitch, which is the distance between common electrodes, is 80 μm, and the vertical pixel pitch, which is the distance between gate electrodes, is 240 μm. The width of the common elecrode is 12 μm, which is made to be smaller than the distance between the common elecrodes, 68 μm, which leads to the larger open port rate.

The color filter 20 formed in stripe for RGB colors is formed on the substrate facing against to the substrate on which the thin film transistors are formed. On the color filter 20, the transparent resin 13 for flattening the surface of the color filter is multiply coated. For the material for the transparent resin, epoxy resin is used. The drive LSI is connected to the panel.

The material used for the liquid crystal compound has such a property that the anisotropic property of the refractive index, Δn, is 0.072, the dielectric anisotropy, $\Delta\epsilon$, is 3.7 (ϵ//: 7.4, $\epsilon\perp$: 3.7), the viscosity, h, is 20cp(20°C), and the elasticity constant of the twist, K_2, is 8.4 x 10-8 dyn. Therefore, η/K_2 is 23.9[Gs/(m•m)-]. The material used for the orientation layer is PIQ with its relative dielectric constant, ϵ_{AF}, being 2.8. Therefore, the relation, $(\epsilon_{LC})// > 2\epsilon_{AF}$, holds. The individual rubbing direction of a couple of substrates is parallel to each other, and has an angle 105° ($\phi_{LC1} = \phi_{LC2} = 105°$) against the direction in which the applied electric field is extended. See FIG. 4. The gap d between the substrates is formed and controlled with polymer beads dispersed between the substrates so as to be 3.8 μm with liquid crystal filled.

The panel is sandwiched with a couple of polarizers (G1220DU, made by Nitto Electric Co.), and the polarization transmission axis of one polarizer is set to be parallel to the rubbing direction, which means $\phi_{P1} = 105°$, and the polarization transmission axis of the other polarizer is set to intersect perpendicularly with the former polarization transmission axis, which means $\phi_{P2} = 105°$. With this geometrical configuration, the normally-close characteristic of the display pixel can be established.

According to the measurement of the response time of the liquid crystal obtained in the above configuration, the rising-up time is 30 ms, and the falling-down time is 35 ms.

In the above definition, as shown in FIG. 5, the response time is defined to be the time period while the transmission ratio changes required for the 90% fraction of its switching operation between the minimum voltage and the maximum voltage.

[Embodiment 2]

The structure in the embodiment 2 is identical to that of the embodiment 1 excluding the following features.

The material used for the liquid crystal compound is MLC-2011 (made by MELC, Co.) the major component of which is 2, 3-difluorobenzene derivative. In this material, η/K^2 is 27.8 [Gs/(m•m)]. The dielectric anisotropy of the liquid crystal of this embodiment, $\Delta\epsilon$, is -3.3 (E//: 3.1 E$\perp$:7.1). Therefore, the relation, $(\epsilon_{LC})\perp > 2\epsilon_{AF}$, holds. The gap d between the substrates is set to be 4.7 μm, and the retardation, $d \cdot \Delta n$, is determined to be about 0.35 μm.

The individual rubbing direction of a couple of substrates is parallel to each other, and has an angle 15° ($\phi_{LC1} = \phi_{LC2} = 15°$) against the direction in which the applied electric field is extended. See FIG. 4. The panel is sandwiched with a couple of polarizers (G1220DU, made by Nitto Electric Co.), and the polarization transmission axis of one polarizer is set to be parallel to the rubbing direction, which means $\phi_{P1} = 15°$, and the polarization transmission axis of the other polarizer is set to intersect perpendicularly with the former polarization transmission axis, which means $\phi_{P2} = -75°$. With this geometrical configuration, the normally-close characteristic of the display pixel can be established.

According to the measurement of the response time of the liquid crystal obtained in the above configuration, the rising-up time is 38 ms, and the falling-down time is 44 ms.

[Embodiment 3]

The structure in the embodiment 3 is identical to that of the embodiment 1 excluding the following features.

The material used for the liquid crystal compound is MLC-2009 (made by MELC, Co.) the major component of which is 2, 3-difluorobenzene derivative. In this material, η/K_2 is 44.0 [Gs/(m•m)]. The dielectric anisotropy of the liquid crystal of this embodiment, $\Delta\epsilon$, is -3.4 (ϵ//: 3.9 $\epsilon\perp$: 7.3). Therefore, the relation, $(\epsilon_{LC})\perp > 2\epsilon_{AF}$, holds. The gap d between the substrates is set to be 2.0 μm, and the retardation, $d \cdot \Delta n$, is determined to be about 0.30 μm.

The individual rubbing direction of a couple of substrates is parallel to each other, and has an angle 15° ($\phi_{LC1} = \phi_{LC2} = 15°$) against the direction in which the applied electric field is extended. See FIG. 4. The panel is sandwiched with a couple of polarizers (G1220DU, made by Nitto Electric Co.), and the polarization transmission axis of one polarizer is set to be parallel to the rubbing direction, which means $\phi_{P1} = 15°$, and the polarization transmission axis of the other polarizer is set to intersect perpendicularly with the former polarization transmission axis, which means $\phi_{P2} = -75°$. With this geometrical configuration, the normally-close characteristic of the display pixel can be established.

According to the measurement of the response time of the liquid crystal obtained in the above configuration, the rising-up time is 40 ms, and the falling-down time is 20 ms.

[Embodiment 4]

The structure in the embodiment 4 is identical to that of the embodiment 1 excluding the following features.

The material used for the liquid crystal compound is LIXON-5023 (made by Chisso, Co.) the major component of which is 2, 3-difluorobenzene derivative. In this material, η/K_2 is 42.0 [Gs/(m•m)]. The dielectric anisotropy of the liquid crystal of this embodiment, $\Delta\epsilon$, is 4.5 (ϵ//: 8.2 $\epsilon\perp$: 3.7). Therefore, the relation, $(\epsilon_{LC})// > 2\epsilon_{AF}$, holds. The gap d between the substrates is set to be 3,5 μm, and the retardation, $d \cdot \Delta n$, is determined to be about 0.28 μm.

According to the measurement of the response time of the liquid crystal obtained in the above configuration, the rising-up time is 25 ms, and the falling-down time is 30 ms.

[Embodiment 5]

The structure in the embodiment 5 is identical to that of the embodiment 1 excluding the following features.

The material used for the liquid crystal compound is a material disclosed in Japanese Laid-Open Patent No. 2-233626 (1990), (made by Chisso, Co.) the major component of which is 3, 4, 5-trifluorobenzene derivative. In this material, h/K2 is 23.6 [Gs/(m•m)]. The dielectric anisotropy of the liquid crystal of this embodiment, $\Delta\epsilon$, is 7.3 (ϵ//: 11.0 $\epsilon\perp$: 3.7). Therefore, the relation, $(\epsilon_{LC})// > 2\epsilon_{AF}$, holds. The gap d between the substrates is set to be 4.7 μm, and the retardation, d•Δn, is determined to be about 0.34 μm.

According to the measurement of the response time of the liquid crystal obtained in the above configuration, the rising-up time is 28 ms, and the falling-down time is 53 ms.

[Comparison Example 1]

The structure in the comparison example 1 is identical to that of the embodiment 1 excluding the following features.

The material used for the liquid crystal compound is ZLI-2806, the major component of which is <h>. In this material, h/K2 is 46.2 [Gs/(m•m)]. The dielectric anisotropy of the liquid crystal of this comparison example, $\Delta\epsilon$, is -4.8 (ϵ//: 3.3 $\epsilon\perp$: 8.1). Therefore, the relation, $(\epsilon_{LC})\perp > 2\epsilon_{AF}$, holds. The gap d between the substrates is set to be 6.2 μm, and the retardation, d•Δn, is determined to be about 0.27 μm.

The individual rubbing direction of a couple of substrates is parallel to each other, and has an angle 15° ($\phi_{LC1} = \phi_{LC2} = 15°$) against the direction in which the applied electric field is extended. See FIG. 4. The panel is sandwiched with a couple of polarizers (G1220DU, made by Nitto Electric Co.), and the polarization transmission axis of one polarizer is set to be parallel to the rubbing direction, which means $\phi_{P1} = 15°$, and the polarization transmission axis of the other polarizer is set to intersect perpendicularly with the former polarization transmission axis, which means $\phi_{P2} = -75°$. With this geometrical configuration, the normally-close characteristic of the display pixel can be established.

According to the measurement of the response time of the liquid crystal obtained in the above configuration, the rising-up time is 150 ms, and the falling-down time is 180 ms.

[Comparison Example 2]

The structure in the comparison example 2 is identical to that of the embodiment 1 excluding the following features.

The material used for the liquid crystal compound has such a property that the anisotropic property of the refractive index, Δn, is 0.0743, the viscosity, η, is 20cp(20°C), and the elasticity constant of the twist, K_2, is 4.17 mdyn. Therefore, η/K_2 is 48.0 [Gs/(m•m)]. The dielectric anisotropy of the liquid crystal of this comparison example, $\Delta\epsilon$, is -1.5 (ϵ//: 3.2 $\epsilon\perp$: 4.7). Therefore, the relation, either of (ϵLC)// > 2eAF or $(\epsilon_{LC})\perp > 2\epsilon_{AF}$ does not hold. The gap d between the substrates is set to be 3.8 μm, and the retardation, d•Δn, is determined to be about 0.28 μm.

According to the measurement of the response time of the liquid crystal obtained in the above configuration, the rising-up time is 100 ms, and the falling-down time is 120 ms.

In FIG. 7, the relationship between the response speed and the ratio of the viscosity of the liquid crystal to the elasticity constant of the liquid crystal is shown in the embodiments and the comparison examples of the present invention.

According to the present invention, by means of making the gap between the substrates facing to each other less than or equal to 6 μm, a high-speed horizontal electric field method can be attained. In addition, by adjusting the material property of the liquid crystal layer and the orientation layer so as to satisfy the formula (1) and (2), the response time of the liquid crystal in the horizontal electric field method can be reduced. As a result, an active matrix type liquid crystal display apparatus using horizontal electric field method which allows mouse-compatible or enables motion picture resolution can be obtained.

Claims

1. A liquid crystal display apparatus, comprising
a pair of substrates (1), at least one of which is transparent;
a liquid crystal composite layer being between said substrates (1);
an orientation control layer (6) for controlling an orientation of a liquid crystal molecule (5);
electrodes (3,4) on said substrates (1) for applying an electric field, mainly parallel to said substrates (1);
a polarization means (2); and
a drive means;
wherein a gap (d) between said substrates (1) is less than or equal to 6 μm, and a response time is less than or equal to 100 ms, and greater than or equal to 1 ms.

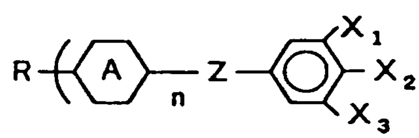
2. A liquid crystal display apparatus, comprising
a pair of substrates (1), at least one of which is transparent;
a liquid crystal composite layer being between said substrates (1);
an orientation control layer (6) for controlling an orientation of a liquid crystal molecule (5);
electrodes (3,4) on said substrates (1) for applying an electric field, mainly parallel to said substrates (1);
a polarization means (2); and
a drive means;
wherein a relationship between a dielectric constant of a liquid crystal composite material layer, (-$(\epsilon_{LC})//$: dielectric constant measured in a longitudinal axis of a molecule, $(\epsilon_{LC})\perp$: dielectric constant measured in a transverse axis of a molecule (5)), and a dielectric constant of the orientation control layer (6), (ϵ_{AF}), holds an equation (1),

$$(\epsilon_{LC})// > 2\epsilon_{AF}, \text{ or } (\epsilon_{LC})\perp > 2\epsilon_{AF}, \qquad (1)$$

and a relationship between viscosity of a liquid crystal composite material layer, η, and an elasticity constant of a twist, K_2, holds an equation (2),

$$\eta/K_2 < 4.5 \times 10^{10}[s \cdot m^{-2}], \qquad (2)$$

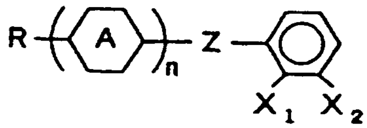
3. A liquid crystal display apparatus of Claim 1, wherein said liquid crystal composite material is made to include liquid crystal chemical compound represented by a general chemical formula (I), in which fluoro group or cyano group, or both of them coexist as an end group.



(I)

(In (I), X_1, X_2 and X_3 are fluoro group, cyano group, or hydrogen atom; R is alkyl group or alkoxyl group having the carbon number 1 to 10 which is replaceable; Ring A is cyclohexane ring, benzene ring, dioxane ring, pyrimidine ring, or [2, 2, 2]-bicyclooctane ring; Z is single bonding, ester bonding, ether bonding, or methylene, or ethylene; and n is an integer, 1 or 2.)

4. A liquid crystal display apparatus of Claim 1, wherein said liquid crystal composite material is made to include liquid crystal chemical compound represented by a general chemical formula (II), in which fluoro group or cyano group, or both of them coexist as an end group.



(II)

(In (II), X_1 and X_2 are fluoro group, cyano group, or hydrogen atom; R is alkyl group or alkoxyl group having the carbon number 1 to 10 which is replaceable; Ring R is cyclohexane ring, benzene ring, dioxane ring, pyrimidine ring, or [2, 2, 2]-bicyclooctane ring; Z is single bonding, ester bonding, ether bonding, or methylene, or ethylene; and n is an integer, 1 or 2.)

5. A liquid crystal display apparatus of Claims 1 to 4, wherein a retardation of a liquid crystal composite material layer, $d \cdot \Delta n$, is greater than or equal to 0.21 µm, and less than or equal to 0.36 µm.

FIG. 1(a)

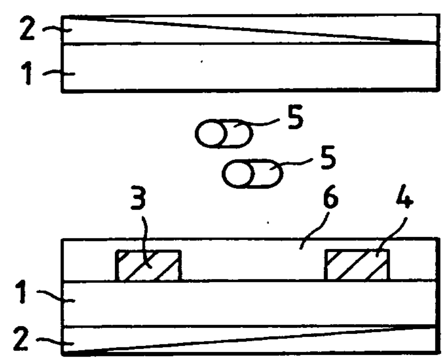


FIG. 1(b)

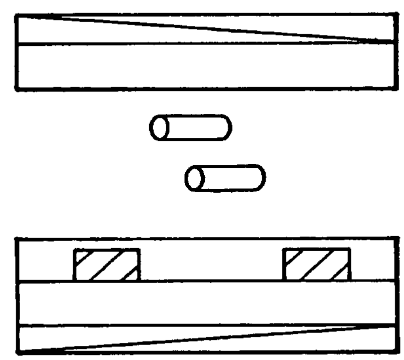


FIG. 1(c)

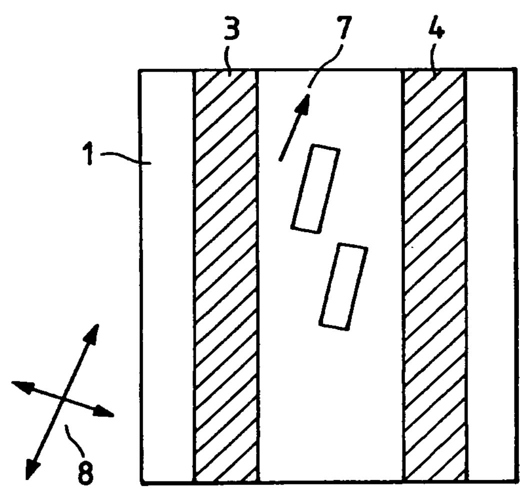


FIG. 1(d)

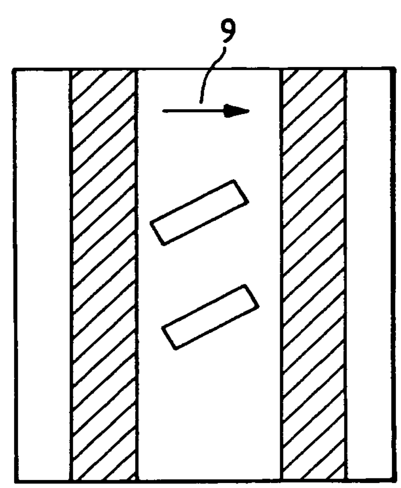


FIG. 2

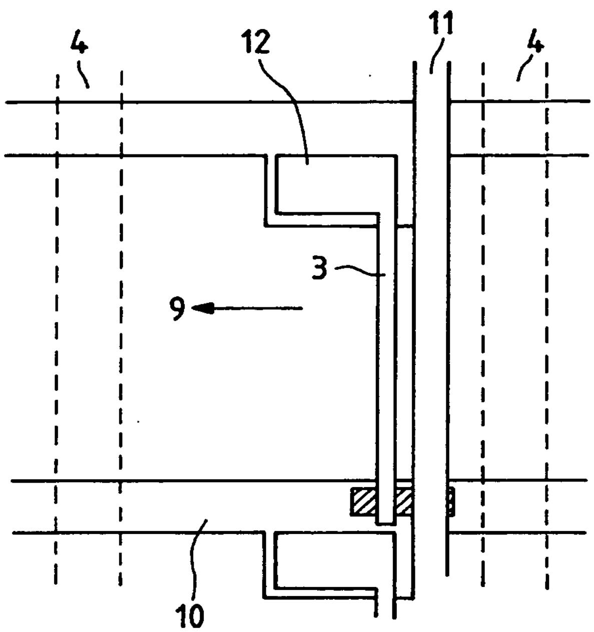


FIG. 3

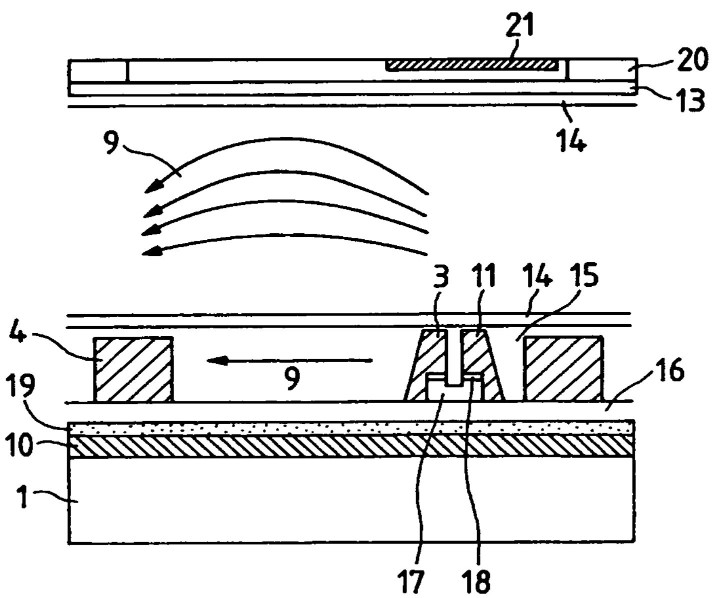


FIG. 4

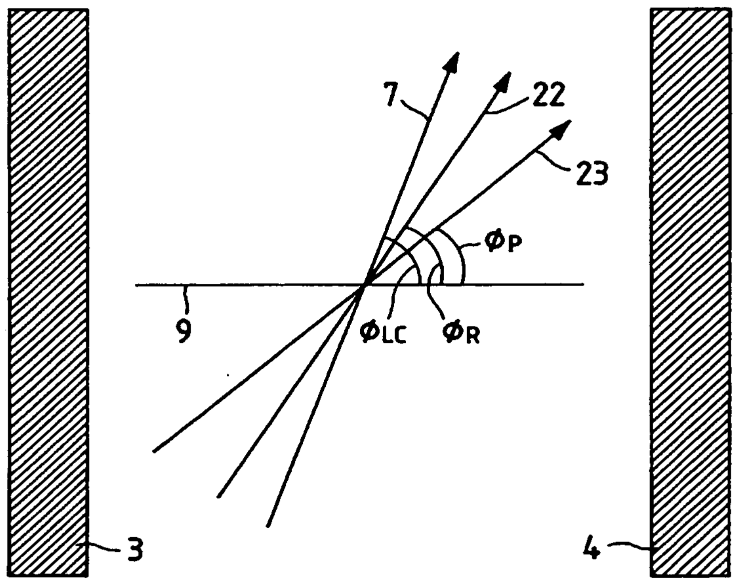

7
22
23
ØP
9
ØLC
ØR
3
4

FIG. 5

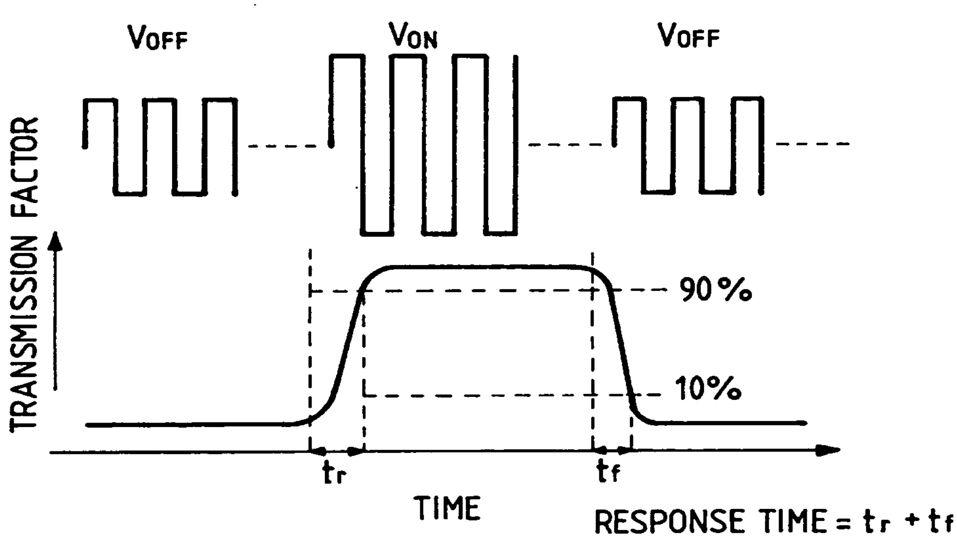

VOFF
VON
VOFF
TRANSMISSION FACTOR
90%
10%
tr
tf
TIME
RESPONSE TIME = tr + tf

FIG. 6

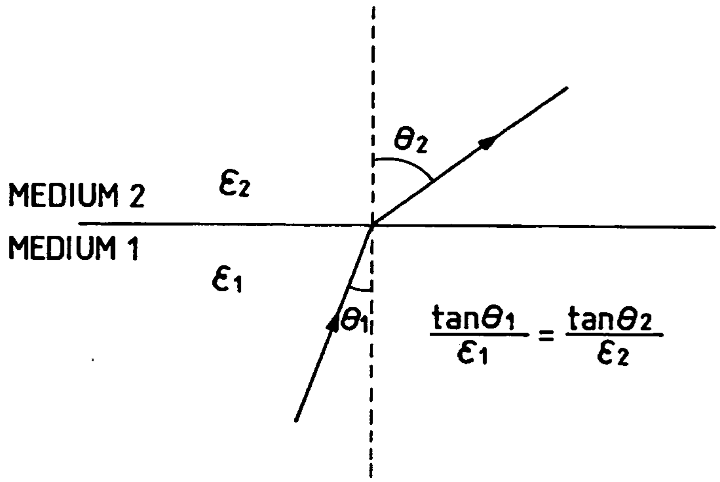
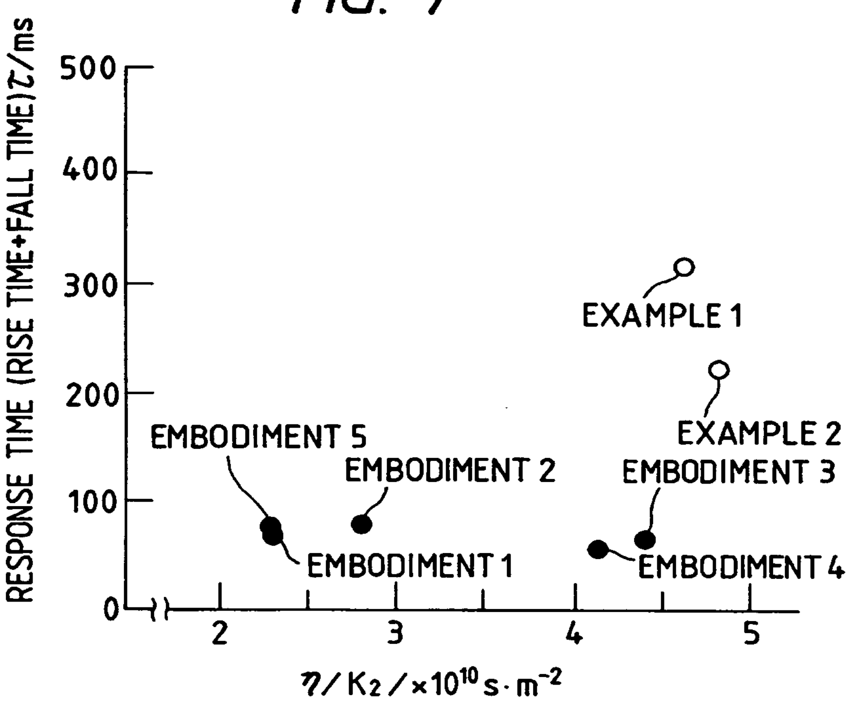

MEDIUM 2
MEDIUM 1
ε_2
ε_1
θ_2
θ_1
$\frac{\tan\theta_1}{\varepsilon_1} = \frac{\tan\theta_2}{\varepsilon_2}$

FIG. 7


RESPONSE TIME (RISE TIME+FALL TIME) τ/ms
500
400
300
200
100
0
2
3
4
5
$\eta / K_2 / \times 10^{10}\, s \cdot m^{-2}$
EXAMPLE 1
EXAMPLE 2
EMBODIMENT 5
EMBODIMENT 2
EMBODIMENT 3
EMBODIMENT 1
EMBODIMENT 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 20 0479

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	WO-A-91 10936 (FRAUNHOFER GES FORSCHUNG) 25 July 1991	1	G02F1/1343
A	* page 15, paragraph 2 - page 17, paragraph 3 * * page 24, last paragraph - page 25, paragraph 1; claims 16-19; figures 1,2 * ---	2-5	
D,A	US-A-4 345 249 (TOGASHI SEIGO) 17 August 1982 * column 8, paragraph 3; figure 7 * ---		
P,X	EP-A-0 588 568 (HITACHI LTD) 23 March 1994 * figures 4,5; examples 2,3 * -----	1,5	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
G02F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	12 May 1995	Wongel, H

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